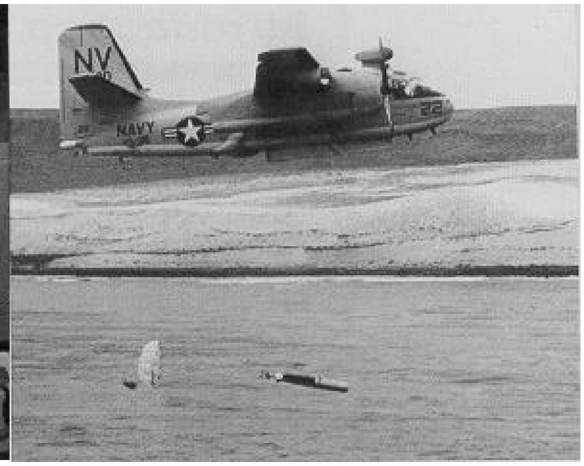


NEW DIRECTIONS AND MISSIONS: THE NINTEEN SIXTIES

Introduction

The 1960s redefined the role and structure of the Navy laboratories. Beginning in 1961, Secretary of Defense McNamara directed reforms that centralized authority and systemized management of the laboratories. Authority was moved from the bureaus to the Chief of Naval Material. Management reforms, styled along corporate lines, linked planning and budgeting.

Deputy Director of Defense Research and Engineering, Dr. Chalmers Sherwin, recommended that the laboratories be consolidated into self-contained "core laboratories" that could perform work across the entire R&D spectrum.

Rapidly changing technology also changed the scope of work done at the laboratories. Advances in solid-state electronics and digital circuitry, for example, offered a quantum increase in reliability and computing. The growing need for successively higher levels of command to obtain reliable combat information and to direct forces called for new systems in command control; to meet that need, NEL engineers developed the Command Ship Data System (CSDS), the Fleet Flag Data System (FFDS), and the Integrated Flagship Data System (IFDS). Lasers emerged as a new technology, and NEL focused on the potential of lasers for communications. Ocean technology developed rapidly in the 1960s; keeping pace with that development, NEL participated in several historic missions of the bathyscaph *Trieste*. NEL and NOTS also participated in Sealab II, and NOTS developed several vehicles for manned and unmanned undersea operations. Also during the sixties, the advent of nuclear submarines placed new demands on the torpedo program; to meet those demands, NOTS developed the Mk 46.

On 1 July 1967, mergers produced a dramatic reorganization of Navy laboratories. NOTS Pasadena became the Naval Undersea Warfare Center (NUWC), with a branch in San Diego. Also, that portion of NEL devoted to undersea research was made a part of the newly established NUWC branch in San Diego. NEL, in line with its new mission, was renamed the Naval Command Control and Communications Laboratory Center (NCCCLC); within a year, NCCCLC became the Naval Electronics Laboratory Center (NELC).

The McNamara Era

Redefining the Role of Navy Laboratories

Beginning in the 1960s, President Kennedy's Defense Secretary, Robert McNamara, directed a series of reforms that eventually changed the role and structure of the Navy's laboratories. In brief, the McNamara reforms attempted to reorganize DoD laboratories under corporate lines, but they also sought to curtail interservice rivalry and reduce duplication of effort by concentrating more authority in the Office of the Secretary of Defense (OSD).

Upon taking office in 1961, Secretary McNamara submitted a long list of questions to his subordinates. Question 97 ran as follows: "Advise me on ways in which to improve the operations of the in-house laboratories." The Task 97 Action Group reported that the laboratories played a vital role in national security:

- They could investigate rapidly changing technologies for their applicability to military problems. Simultaneously, they could bring military needs to the attention of the general scientific and technical community.
- They enabled the services to be "smart buyers" of contract R&D.
- They managed and helped manage weapons systems development and test programs.
- They developed a cadre of technically proficient military officers necessary in the modern armed forces.

Funding was just one area cited for improvement. The Task 97 Action Group reported that technical directors wanted more discretionary funding. Navy laboratories depended too much on bureau sponsors, were losing touch with the cutting edge of science, and were having troubles attracting top scientists. Obtaining sponsor support required excessive time from technical personnel. Managers complained that laboratories were being turned into "job shops" and were spending more time managing contracted work rather than researching challenging and broadly defined assignments.

Task 97 recommendations led the Navy to establish independent research (IR) as a budget line item in 1964. Similarly, in 1963, the bureaus had been directed to establish independent exploratory development (IED) as a budget line item. The laboratories were authorized to initiate certain exploratory development on their own, without having to obtain bureau approval. Both BuShips and BuWeps established IED programs in 1964, directing that IED funds were to be used to support work in assigned mission areas.

Core Laboratories: Centers of Excellence

The Navy continued to look for various ways to improve the laboratories. In 1964, the Deputy Director of Defense Research and Engineering, Dr. Chalmers Sherwin, proposed a series of sweeping reforms. Key recommendations included the following: (1) group the laboratories into functional centers with broad military problem-oriented missions and satellite laboratories reporting to the laboratory centers; (2) consolidate the 13 existing laboratories into 9 new centers, all placed under a Director of Navy Laboratories (DNL), who would allocate manpower, facilities, supporting funds, and funding for the core mission(s) of each center; (3) place each laboratory under a civilian scientist or engineer reporting to the Assistant Secretary for R&D; (4) perform work in each laboratory across the entire spectrum of basic research, applied research, systems design and fabrication, in addition to engineering design of systems; (5) divide funding equally between the laboratories' "core" program (that is, block-funded independent of sponsors in Washington) and programs that were "customer-funded" (that is, paid for specifically by Washington-based sponsors).

As the idea of "core laboratories" developed, a technical center was defined as a self-contained laboratory of more than 1000 specialists who could perform basic research, develop feasibility models, and oversee systems developments.

Director of Navy Laboratories (DNL)

On 20 December 1965, the position of Director of Navy Laboratories was established. Although the charter granted DNL control of the in-house exploratory development program, the charter did not provide DNL with funds to control this portion of the budget. The material bureaus (and their successors, the systems commands) retained control of most of this budget. In reality, the Office of DNL could not materially influence technical programs because the programs were not funded by DNL. Hence, DNL became more a coordinator of research administration than a research director with line authority.

From Bureau to Chief of Naval Material (CNM) Management

On 15 March 1966, responsibility for the management of the bureau laboratories was moved from the bureaus to the Chief of Naval Material (CNM), an admiral reporting to CNO. This move reflected McNamara's view that the functions of the laboratories should be broadened beyond the interests of the bureaus. On the one hand, the laboratories should have more discretionary funding, so that they would not depend entirely on sponsors. On the other hand, they needed more supervision, so the services and the material agencies within the services would not duplicate each other's work. McNamara's management team had several rationales for the transfer of Navy laboratories from the sponsoring bureaus to CNM. First, they thought that shifting the laboratories from their previous bureau sponsors to an independent authority would free the laboratories from overly narrow concerns. Second, centralized control would eliminate duplication of effort and provide OSD with greater oversight. Direct military supervision of the laboratories remained in the form of CNM. However, the long-standing sponsor-project manager relationships endured.

The bureaus were replaced by a new series of systems commands, SYSCOMS, whose heads reported to CNM, who reported directly to the CNO, rather than directly to the Secretary of the Navy. Now, the uniformed head of the Navy, CNO, had full command authority over commands, naval districts, and the former bureaus. The four material bureaus became six systems commands: the Ordnance Systems Command, Sea Systems Command, Supply Systems Command, Electronic Systems Command, Air Systems Command, and Facilities Engineering Command.

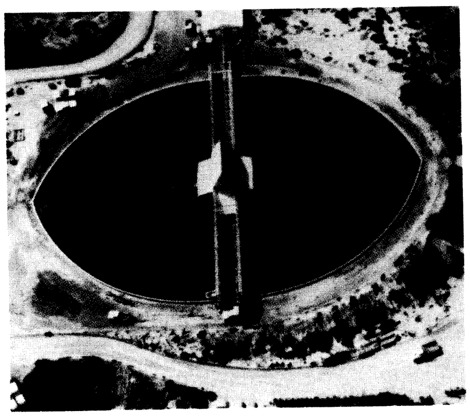
Naval Industrial Fund (NIF)

The effort to impose corporate management-style methods carried over into funding. Among the themes most prominent in the studies of Navy laboratories during the 1960s was that the funding of R&D was fragmented and encouraged duplication and excessive management. Severe restrictions on reprogramming (i.e., shifting funds appropriated for one purpose to another project) and uncertainties over funding from year to year contributed to waste, delay, and rigid financial controls. To remedy these problems, the Navy converted the laboratories to the Navy Industrial Fund (NIF). Customers were charged the full cost of products and services. These costs, compared with industry, provided a measure of the laboratories' efficiency. Originally, the NIF system developed at docks and yards, where labor and material charges were paid for by the districts of which they were a part. For the laboratories, NIF was to make them more businesslike since true costs could be estimated from specific line items instead of general overhead.

NEL Growth

The late 1950s and the first half of the 1960s saw a steady growth in the size of NEL. By 1965, NEL had grown to more than 1500 civilian billets and 150 military, about 300 above the low point of the mid-1950s (between 1100 and 1200). NEL's budget quadrupled from $10 million annually to over $40 million. Since staffing did not rise on the same scale as spending, the increased volume of projects required more contracting of work.

During this time, NEL's mission encompassed three technology areas: (1) undersea technology, including underwater acoustics, surveillance, mine warfare, submarine navigation, and physical oceanography; (2) electromagnetics, including propagation research, electronic warfare, satellite communications, VLF radio navigation, and radars; and (3) computer systems development and computer languages, including data processing in general but also shipboard computer-driven information and command and control systems.



TRANSDEC. Opened in 1964, this freshwater anechoic pool allowed NEL engineers to make extremely accurate measurements of transducers.

New NEL Facilities

Transducer Evaluation Center (TRANSDEC)

In 1960, the owner of Sweetwater Lake, the California Water and Telephone Company, began to lower the level of the lake. To continue using the calibration station there, NEL would have had to relocate all its buildings, so in 1962, the laboratory began building a freshwater anechoic pool on the ocean side of Catalina Boulevard.

The original concept for the Transducer Evaluation Center (TRANSDEC) was developed by NEL employee Charles E. Green. Green, holder of several patents on the design of the pool, began experimenting with the basic principle of TRANSDEC in the early 1950s. He proposed use of his design for a man-made elliptical pool to replace the facilities at Sweetwater Lake. Since no suitable natural lake was available, Green's design seemed ideal. It also eliminated problems of off-station management, security, and transportation.

Opened in 1964, TRANSDEC achieved what had never been possible at Sweetwater Lake, a simulation of an "infinite" expanse of water free from echoes (that is, anechoic). The design eliminated all extraneous man-made or natural biologic noises and permitted precise control of surface and subsurface conditions. NEL engineers could make extremely accurate measurements of transducers used in their systems.

For his part in TRANSDEC, Green was awarded a Presidential Citation in 1964 by President Lyndon B. Johnson.

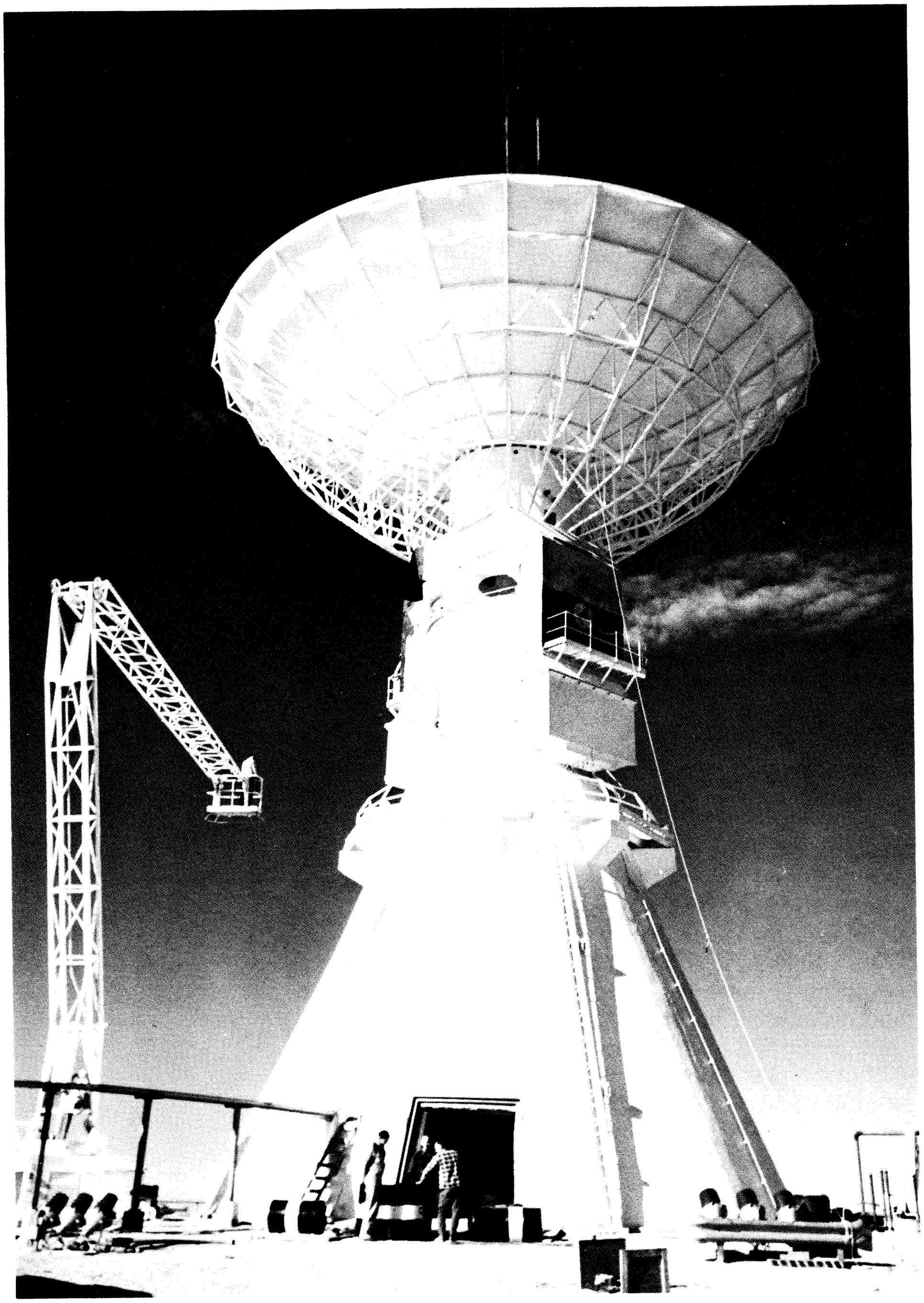
Parabolic Radio Telescope

In 1961, to support the satellite communications programs and radio physics research in general, NEL built on Point Loma a 60-foot solid parabolic antenna reflector on a reinforced concrete tower. NEL also built an adjacent 28-foot reflector. Both the big dish and the 28-foot reflector were used in super-high frequency experiments in 1964, the first of a long series of such experiments. During the Vietnam War, the 60-foot antenna also served as a relay in a secure data system.

Parabolic Radio Telescope. This 60-foot-diameter, solid parabolic antenna reflector was built to support satellite communications programs and radio physics research.

Astro-Geophysical Observatory

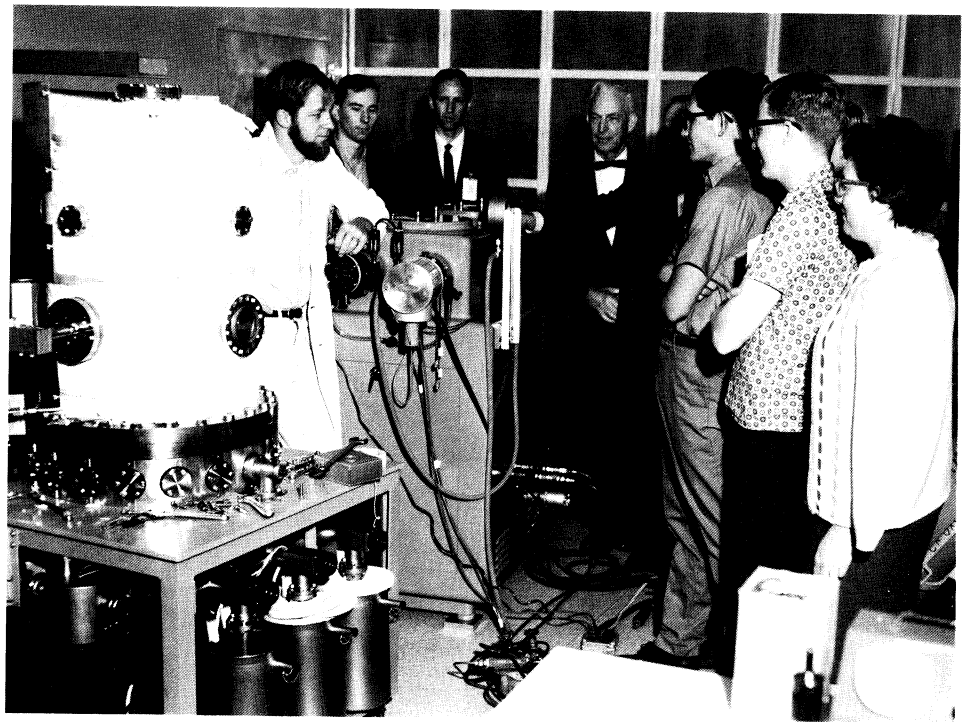
To support Navy and Air Force communications satellite programs with research in propagation and ionospheric forecasting, NEL built an astro-geophysical observatory 65 miles east of San Diego at La Posta, California. Begun in May 1964, the observatory was completed a little over a year later. Unlike the mirror radio telescope on Point Loma, the La Posta mirror antenna could transmit as well as receive. Located atop a 3900-foot site in the Laguna Mountains about 6 miles northeast of Campo, California, the observatory was operated jointly with the Air Force and used in joint studies with a similar structure built by NRL at Waldorf, Maryland. The observatory had to be located in an unpopulated area that was free of hazardous radiated energy levels and that provided an environment for ultrasensitive reception, free from noise and interference. During the 1960s, the observatory played a major role in solar radio mapping, studies of environmental disturbances, and development of a solar optical videometer for microwave research.



Astro-Geophysical Observatory, La Posta, CA. The mirror antenna at La Posta supported research in propagation and ionospheric forecasting.

Microelectronics Laboratory

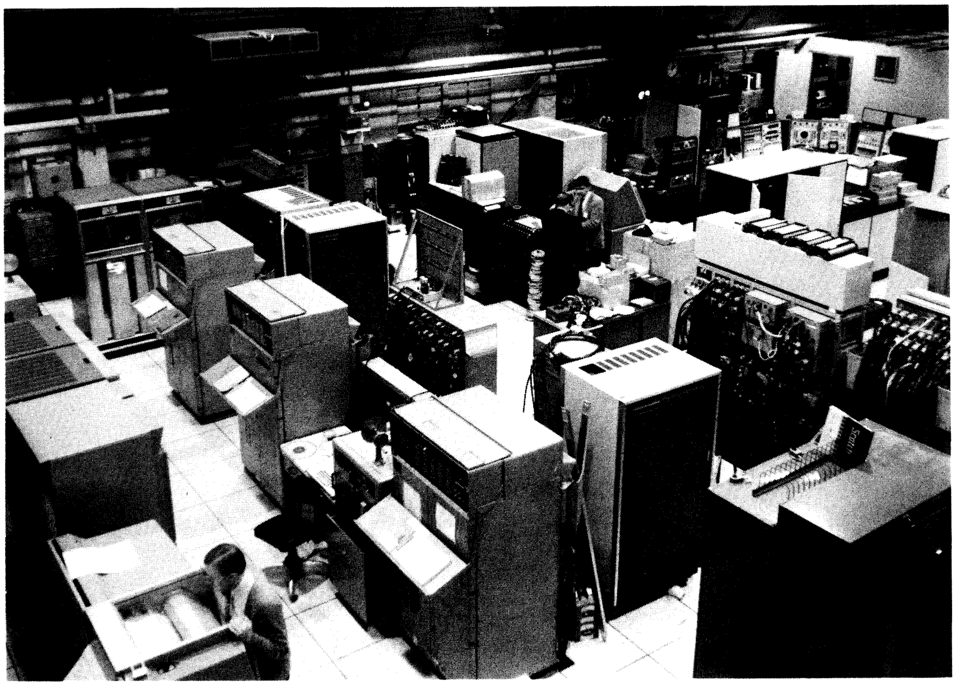
During the mid-1960s, NEL converted a portion of Battery Ashburn into a secure communications laboratory and another portion into a microelectronics laboratory that would support a wide range of systems using the new digital technology. Already naturally shielded from electromagnetic interference, the heavy concrete of Battery Ashburn continues to provide a vibration-free environment with a naturally stable ambient temperature. A laminar-flow air-filtering system gives the laboratory several "clean rooms" in which the air is kept free from particles as small as 0.3 micron.



Microelectronics Laboratory, 1968. Dr. Carl Zeisse (far left) describes the laboratory's unique capabilities to visitors.

Applied Systems Development and Evaluation Center (ASDEC)

During the 1960s, NEL built the Applied Systems Development and Evaluation Center (ASDEC), the first Navy facility specifically intended to accommodate systems developments in the new era of computer technology. A 5400-square-foot open-shop facility, ASDEC was a full-scale mockup of a shipboard combat information center, consisting of interactive displays, data-processing equipment, and communications. ASDEC was located in wing 1 of NEL's main building. Built around an NTDS-like system, ASDEC was linked to sensor systems that provided live radar, live digitized data, and live voice information. ASDEC served as a general purpose testbed where computer-based data systems could be assembled, programmed, and debugged in settings similar to their intended operational use. Although real sensor data were sometimes used, most of the sensor inputs came from various simulators developed by NEL scientists. By 1970, ASDEC was increasingly used for software development.



ASDEC. This 5400-square-foot facility provided a full-scale mockup of a shipboard combat information center.

NOTS Pasadena Growth

During the early 1960s, NOTS Pasadena had approximately 1000 people—800 of them civilians, a few officers, and nearly 200 sailors. In 1965, its annual budget exceeded $41 million. With its proximity to Caltech, the University of Southern California, the Claremont Colleges, and UCLA, NOTS Pasadena encouraged its staff to pursue graduate studies in work-related fields and to use nearby academic expertise through research contracts in hydrodynamics, signal processing, and mathematics. NOTS Pasadena and NEL had begun to have closer contacts during the early 1960s. Representatives from both organizations participated in joint working groups as well as panels concerned with technical issues such as sonar and ASW weapons systems and with administrative issues such as civil service regulations and military construction.

Reorganization

By 1966, the Naval Material Command concluded that Pasadena facilities were no longer adequate to support its missions. Also, a Defense Science Board committee had recommended that the Navy establish a development center for ASW-surface weapons. The Navy studied various sites, including Los Alamitos, Santa Barbara, and San Diego, for a new West Coast undersea center.

Meanwhile, the decision was made to consolidate the 15 Navy laboratories into 9. Laboratories at Corona, California; Brooklyn, New York; and San Francisco, California, were shut down. Elsewhere, mission assignments were realigned, and names were changed to reflect the new roles given remaining laboratories. NOTS China Lake merged with the Corona laboratory and became the Naval Weapons Center (NWC).

Naval Undersea Warfare Center (NUWC)

On 1 July 1967, NOTS Pasadena (with its specialty in underwater ordnance) merged with NEL's undersea technology element to form the Naval Undersea Warfare Center (NUWC). In October 1967, the Marine Biosciences Facility at Point Mugu, CA, was transferred to NUWC from the Naval Missile Center. The newly established Center was to be the prototype of the core laboratory proposed by Dr. Chalmers Sherwin and others. Dr. William McLean, Technical Director of NOTS China Lake and famed for inventing the Sidewinder antiaircraft missile, became the first Technical Director of NUWC. Douglas Wilcox, Assistant and later Associate Technical Director at Pasadena, continued as senior civilian at NUWC Pasadena and reported directly to Dr. McLean, who preferred to temporarily keep his own office at China Lake. Captain G. H. Lowe, formerly Officer in Charge of NOTS Pasadena for 4 years and Commander of NOTS China Lake for 5 months, was selected as Commanding Officer of NUWC.

The San Diego branch of NUWC used existing NEL facilities, and most NEL researchers who joined the NUWC staff remained in their same offices. The head of what had been NEL's Undersea Technology Department, Dr. Donald Wilson, became head of the San Diego branch of NUWC and moved from Building 33 Topside to the bayfront area. On 1 July 1968, NUWC's official headquarters transferred from Pasadena to San Diego. The merger of ASW groups made sense: With digitized data certain to play a greater role in ASW, computerized systems would have to "talk" to one another. By putting scientists and engineers in these related fields together, interfaces between submarine detection systems and antisubmarine weapons systems would be easier to develop.

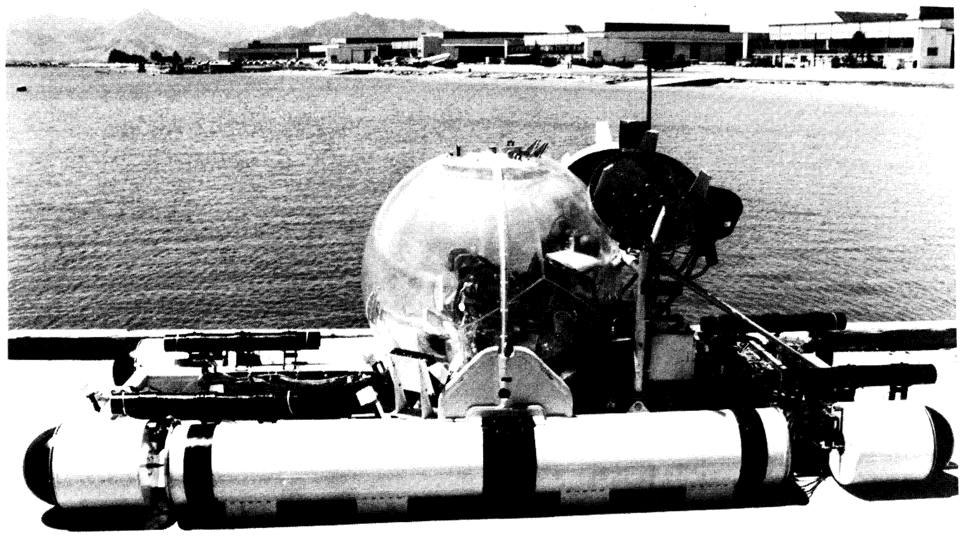
The reorganization brought with it additional recognition for ASW and ocean engineering. Recognition led to increased sponsorship and military construction funds. In 1969, the military systems analysis function of the Naval Radiological Defense Laboratory (NRDL) was also assigned to the Center when NRDL was disestablished.

Dr. McLean decided to establish a satellite NUWC laboratory in Hawaii because its surrounding warm waters would provide year-round access for R&D in two areas of particular interest to him: marine biosystems and manned submersibles. In 1967, representatives from NUWC chose a site on Oahu adjacent to the Marine Corps Air Station at Kaneohe Bay. At the time, the real estate consisted of one unused hangar and a few acres with waterfront access.

Originally staffed by former "China Lakers," the facility was officially dedicated in 1968. Jesse Burkes, a retired Navy Captain with the title of Area Director, headed a staff of 35. Over the years, the Hawaii laboratory increased in size and stature, growing to 25 acres and nearly 200 employees by the time it celebrated its 20th anniversary.

Among the manned submersibles developed or tested in Hawaii were Dr. McLean's *Hikin*, the original two-man acrylic submarine and the follow-on improved acrylic, two-man *Makakai* (Hawaiian for "eye of the sea"), a 600-foot Navy certified submersible designed for oceanographers and marine biologists to observe the sea directly. Like the parent laboratory, the Hawaii laboratory was to become the site for significant research in advanced remotely operated vehicles (ROVs) and work systems packages: The Remote Unmanned Work System (RUWS) was a technology development program and the forerunner to the Advanced Tethered Vehicle (ATV). Both programs will be discussed later.

The Makakai *two-man submersible. The acrylic sphere afforded the operator and passenger an unobstructed, panoramic view of the outside surroundings, an enormous advantage over viewports in traditional submersibles.*



Hawaii Laboratory. NUWC established the Hawaii laboratory in 1967 to pursue work in marine biosystems and manned submersibles. (1971 photo)

New Name for NUWC

The name "Naval Undersea Warfare Center," though it explained the rationale for the new laboratory in San Diego, proved a liability in the political climate of the late 1960s. Finding their invitations to conferences drying up and campus recruitment declining, NUWC scientists and engineers blamed their institutional affiliation. Their concern led to a new name for the Center. In 1969, NUWC was renamed the Naval Undersea Research and Development Center (NURDC).

New Names for NEL

In keeping with the reorganization program of 1967, NEL was formally renamed the Naval Command Control and Communications Laboratory Center (NCCCLC). NEL's Technical Director, Dr. Ralph Christensen, and Commanding Officer, Captain William Boehm, continued at NCCCLC. The new name for the laboratory seemed cumbersome and never gained full acceptance. Hence, in 1968, the name was changed to the Naval Electronics Laboratory Center (NELC).

Work at NELC was to concentrate on command control, communications, surveillance, and related programs. NELC was to assume its new role as a "center of excellence" in digital data links, satellite communications, electronic warfare, tactical data systems, radio, radar, and electronic displays.

Fiscal Year 1969 saw completion of the transfer from NELC of all facilities and equipment related to the undersea research functions. NUWC/NURDC received the Point Loma waterfront property it had occupied up to that time as a tenant under an Intraservice Support Agreement with NELC. By mutual agreement, NELC further transferred those permanently installed research facilities located within the NELC area but used exclusively by NUWC/NURDC. These were the Arctic Research Facility, the Transducer Evaluation Center (TRANSDEC), and the Marine Bio-Acoustic Experimental Facility. In 1969, Battery Whistler was formally renamed the Arctic Submarine Laboratory, and Dr. Waldo Lyon was named its first Director.

New Systems and Research

Submarine Broadcast System

With the success of the Polaris submarine program, the importance of strategic submarine communications increased. Beginning in the early 1960s, NEL and its successors played a central role in the development of Verdin, a VLF/LF communications system designed to provide up to four channels of information for deeply submerged ballistic-missile submarines.

Work on improving VLF radio for the submarine broadcast system continued during the 1960s and 1970s. Basic studies of ionospheric propagation were central to this work, and NEL established several outstations during the 1960s to support studies of long-range radio transmission. The laboratory conducted these studies at sites located at Sentinel, Arizona; Thule AFB, Greenland; Phoakuloa, Hawaii; and Fairbanks, Alaska. Each location had VLF transmitters and receivers. Their work was "sounding," that is, transmitting VLF signals into the ionosphere at different locations to determine atmospheric interference with VLF transmissions. For example, the Fairbanks, Alaska, site studied the ionosphere during periods when the phenomenon of the Northern Lights (aurora borealis) was most active.

In 1964, scientists developed a technique for separating round-the-world VLF signals from short-path signals at the same frequencies. By 1965, other NEL scientists focusing on the earth's geomagnetic fields had developed new fundamental concepts of modal propagation in a waveguide that had direct applications to the Verdin system. (NOSC today is responsible for improving and enhancing the Verdin system, which includes a fixed shore-based transmitting system, an airborne transmitting system, a processing system, and an automated control system—the combination providing an automated worldwide broadcast system.)

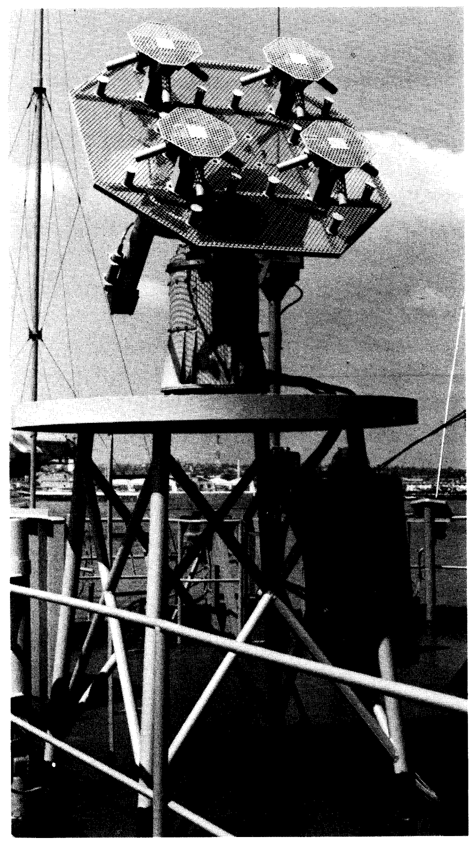
Communications

In Project MAILBUOY in 1962, NEL developed the first UHF communication system. The program continued during 1963 into Project REDGLARE in which a UHF communications repeater in a rocket successfully passed teletype, voice, and facsimile data from ship to shore. Although too costly to serve as a communications system, REDGLARE demonstrated the feasibility of long-range communications through a space-based linkup. As soon as satellites became reliable and affordable in the early 1960s, NEL began work on satellite-based communications systems.

Satellite Communications/ Shipboard Satellite Terminal

NEL radio physicists conducted their first experiments with communications in space in 1960, using the Echo 1 satellite. They continued to experiment with higher frequencies, notably super high frequency (SHF), aboard the communications satellites that became widespread in the decade that followed. The data derived from these tests enabled NEL and others to develop antennas and terminals, so that by 1965 the Navy could operate a satellite communications system for over-the-horizon (OTH) communications.

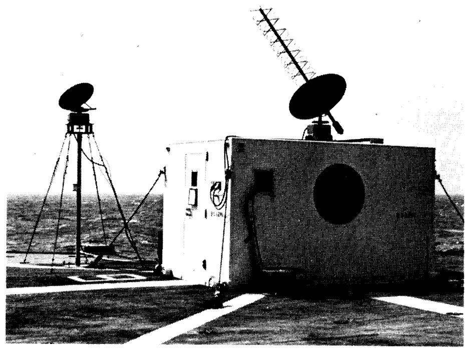
In 1968, NELC designed a shipboard satellite terminal for the cruiser USS *Providence* (CG 6). In 1969, tests aboard the cruiser off Tahiti successfully demonstrated the feasibility of satellite relay of fleet multichannel broadcasts, which were picked up on portable equipment installed aboard *Providence*. The choice of Tahiti, a zone of poor high-frequency reception, showed that the relatively low-cost portable equipment NELC had developed could meet the needs of the Fleet. The equipment on *Providence* was installed by NELC personnel and served as a base for the design of terminals on six ships involved in a Fleet Operational Investigation. The exercise was held in the Atlantic and was the Navy's first large-scale test of satellite communications. At the same time as the exercise was held, satellite transmissions between NELC and the carrier USS *Independence* (CV 62) at Norfolk, Virginia, demonstrated the feasibility of long-distance relay of tactical data via satellite.



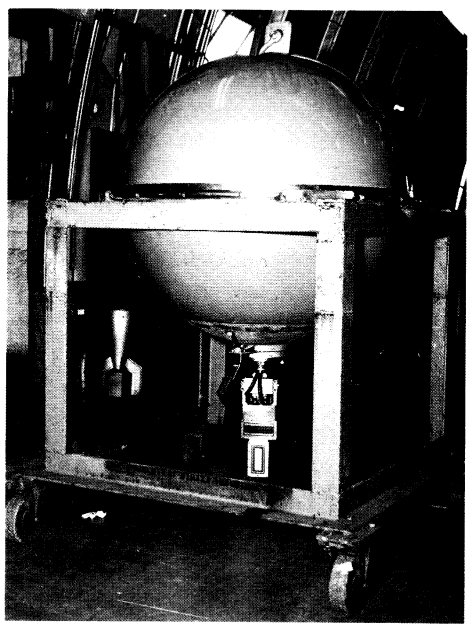
Satellite communications. Shipboard satellite terminal aboard USS Providence *(CG 6).*

Apollo Recovery Exercise

In 1969, NELC successfully applied satellite communications technology to the National Aeronautics and Space Administration's (NASA's) Project Apollo recovery operations. Previously, during Apollo 8 in 1968, atmospheric interference disrupted radio communications. As a result, NASA, in January 1969, asked NELC to develop satellite communications gear to support UHF communications during future Apollo missions, including the one scheduled to land a man on the moon later that summer. Within a month, NELC researchers developed a portable terminal that was flown to Norfolk, Virginia, and deployed aboard the recovery ship, USS *Guadalcanal* (LPH 7). NELC engineers operated the terminal during Apollo 9 as the primary command control circuit between Mission Control at Houston and the recovery areas. NELC engineers operated the terminal during Apollo 10 and Apollo 11 and then transferred the terminal to NASA.



Apollo recovery exercise. Portable terminal aboard the recovery ship, USS Guadalcanal *(LPH 7).*



AN/SQQ-16 towed array. The AN-SQQ-16 was one of the first portable, towed, passive sonars that permitted very-high-resolution target classification.

Sonar Systems

During the 1960s, ocean surveillance research focused on mobile or tactical surveillance, that is, hull-mounted or towed-array sonars used by ASW craft. In 1964, NEL developed the AN/SQQ-16 towed array, one of the first portable, towed, passive sonars that permitted very-high-resolution target classification.

NEL also worked on long-range active detection systems. The research trend was then toward higher power and lower frequencies, but the size, power requirements, and cost of equipment were considerable obstacles. More successful efforts were to harness the power of computing to process signals more efficiently, to raise the "signal-to-noise ratio" (the ability of a sonar to discriminate a target echo from the ambient noise of the oceans), and to handle the resulting data so that ships could use the data operationally.

Equally significant accomplishments were in the field of transducer design, notably transducer modules with their own power amplifiers. NEL acousticians developed theories to predict the performance of transducers in different configurations and in different oceanic conditions and environments.

Radar

By the 1960s, NEL's work in radar had shifted from system development to the interpretation of radar echoes. The goal of this work was to increase detection rates through the analysis of low-level echoes. Signal forming and processing techniques seemed the most promising methods of enhancing radar performance and achieving the necessary correlation function. Electronic beamforming by computer-directed arrays was accepted as the most direct answer to the mechanical problem of stabilizing and rotating the large search radars in use by the late 1950s.

Arctic Submarine Warfare

The success of the transpolar cruises of *Nautilus* and other submarines in the late 1950s brought recognition to NEL and to Dr. Waldo Lyon. In April 1962, in an impressive ceremony at the White House, President Kennedy awarded the Distinguished Federal Civilian Service medal to Dr. Lyon. Mrs. Lyon accepted for her husband, who was absent on a "confidential mission" for the Navy. The timing was fortuitous for Dr. Lyon because he preferred to shun the limelight and go quietly about his work. Dr. Lyon received a certificate hailing him "for a devotion to a concept in which he never lost faith and for his tenacity in pursuing it against formidable technical problems and in the face of discouraging reverses...."

Although much less publicized than the cruise by *Nautilus* 2 years earlier, the cruise of USS *Sargo* (SSN 583) in 1960 proved to be even more significant operationally, since it was the first winter deployment under the polar ice and one of the most demanding. The submarine both entered and left the Arctic via the shallow Bering and Chukchi seas. *Sargo* sailed more than 6000 miles under the ice and surfaced 20 times in the worst imaginable conditions. On 9 February 1960, *Sargo* surfaced at the North Pole.

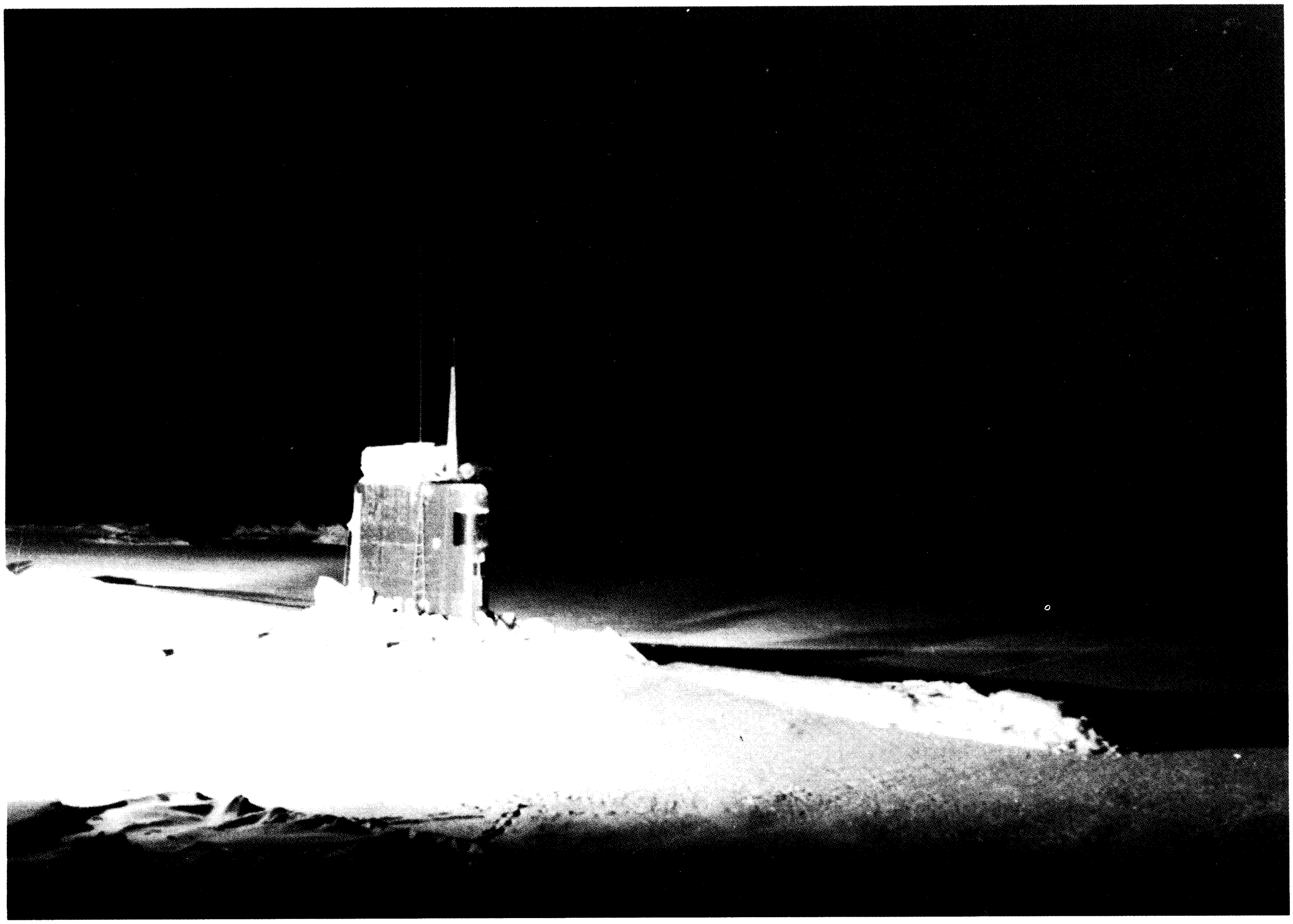
The achievement of *Sargo* would have been impossible but for the seamanship of her navigators and the experimental iceberg detector sonar developed by NEL's High-Resolution Sonar Division and tested by NEL sonar specialists aboard *Sargo* on its 31-day voyage. The iceberg detector detected ice keels even when the nuclear-powered submarine was moving at full speed.

Iceberg detection system developments culminated in the AN/BQS-8 acoustic ice suite that provided the all-around visibility needed for under-ice operations. NEL directed arctic tests of the prototype in the summer of 1962, and CNO approved the ice suite for service use. Production contracts were immediately issued. NEL continued to monitor the contracts, but manufacture passed to contractors and maintenance went to other Navy engineering facilities.

The same basic principles used to develop under-ice sonars were applied to navigation systems for the Arctic. NEL scientists developed an acoustic transponder to serve as an under-ice reference point. Either nuclear- or battery-powered, the transponder was anchored to the bottom of the Arctic Ocean at entrances to known hazardous passages and at intervals along most transarctic routes. The device was first tested in the summer of 1964 and was later used in arctic cruises.

Once Navy submarines had successfully crossed the North Pole, interest in arctic submarine activities faded. The relative lack of interest in arctic submarine warfare after the early 1960s reflected a general view that the important navigation problems of the region had been identified, studied, and filed. Submarine and icebreaker cruises in the Arctic continued but at a reduced rate.

President Kennedy and Mrs. Waldo Lyon at the White House, April 1962. Mrs. Lyon accepted the Distinguished Federal Civilian Service medal on behalf of her husband, Dr. Waldo Lyon.



USS Sargo *(SSN 583) surfaced at the North Pole, 9 February 1960. On the first winter deployment under the polar ice,* Sargo *sailed more than 6000 miles and surfaced 20 times in the worst imaginable conditions.*

Computer Systems

Although nearly 20 years would pass before the popular press heralded the "age of the micro," NEL had appreciated that advances in solid-state electronics and digital circuitry offered a quantum increase in reliability and computing power. Systems could be built based on a computer that could do the following: take data from radars, sonars, and radios; collate, store, and process the data; and then disseminate the data directly to equipment or to displays for human evaluation. In the early 1960s, NEL was able to demonstrate the feasibility of direct digital control of a large weapons system by using the same digital computer that processed the target data.

During this time, NEL also focused on display technology, that is, determining what information is necessary at each level of decision and how best to present that information (for example, whether to print the data on paper or to display it on a screen). NEL computer engineers worked on fiber-optic displays; large-screen displays; high-speed, solid-state matrix displays; and highly specialized circuitry for rapid reviewing of information. Reliability was a major concern, especially of peripheral devices such as printers and magnetic tape drives.

Command Ship Data System (CSDS)

During the early 1960s, NEL engineers developed a specialized command and control system for the National Emergency Command Post Afloat installed aboard the converted command ship USS *Wright* (CC 2). This system, the Command Ship Data System (CSDS), became operational in 1964 and was later adapted to serve Navy Commanders in Chief in Europe and the Western Sea Frontier.

Fleet Flag Data System (FFDS)/Integrated Flagship Data System (IFDS)

Offshoots of the Command Ship Data System were developed to acquire, process, store, and display large quantities of operational data. The best known of these command and control systems was the Fleet Flag Data System (FFDS), which gave the same capabilities to fleet commanders afloat as the parent system had given to the Navy Commanders-in-Chief. The Integrated Flagship Data System (IFDS), which became operational in 1970, extended the same data-handling capabilities to other flagship units.

IFDS. Operator views geographic display aboard USS Providence *(CG 6).*

Automated Data Systems

NEL's pioneering work in automated data systems, particularly the Naval Tactical Data System (NTDS), led to an increasing number of similar projects during the 1960s. NTDS, by assimilating quantities of diverse information in different formats in realtime and presenting the data as a common output, set the standard for Navy automated data systems. The designers of NTDS, by adopting a "building-block" approach, made it possible to reconfigure the system for specialized applications and to adapt it to accommodate other inputs.

Small Ship Combat Data System (SSCDS)

One early application of the building-block approach was the development between 1964 and 1968 of the Small Ship Combat Data System (SSCDS) to apply the same advantages of high-speed automated tactical data processing to ships smaller than those for which NTDS had been designed.

ASW Ship Command Control System (ASWSCCS)

The success of SSCDS led to a specialized command control system for ASW: the ASW Ship Command Control System (ASWSCCS). Work began on ASWSCCS in 1966 and became operational aboard USS *Wasp* (CVS 18) with the Atlantic Fleet in 1968. The success of ASWSCCS led the Navy to designate NELC lead laboratory for the design and development of the larger ASW Force Command Control System.

Navigation: Omega

The low-frequency Radux navigation effort was superseded in 1957 by a new effort to use VLF radio transmissions from widely separated shore stations. The idea of using VLF for navigation stemmed originally from a proposal by J.A. Pierce of Harvard. Pierce hypothesized that a navigation system could obtain accurate position fixes by measuring the phase of a radio wave and by using a frequency band that is phase-stable and little affected by changes in the ionosphere. At that time, the Navy had several different radio navigation systems, each of which was usable only in certain areas. The principal system, Loran, required 57 stations worldwide and yet only managed to cover 10 percent of the earth's surface. Its accuracy was ±2 nautical miles.

Sponsored by BuShips, NEL set to work on Pierce's idea in 1957, and in 1959, conducted extensive tests between Hawaii and California. NEL was lead laboratory throughout and specifically designed the shore station equipment and the first experimental shipboard receiver. The equipment used precisely timed, continuous-wave VLF (between 10.2 and 13.6 kHz/second) pulses from widely separated land-based sites. Receivers could measure phase differences between the four signals to determine lines of position and then plot these against charts to determine location. The advantage of VLF signals is that they do not vary between night and day or according to weather. In addition, VLF signals penetrate the sea to considerable depths and penetrate the polar ice. Between 1960 and 1968, NEL engineers made the system, now named Omega, operational on aircraft, ships, and submerged submarines. The laboratory procured most of the original prototype equipment and furnished the technical support during installation,

Omega station at Bratland, Norway, 1967.

testing, and operation. The Naval Research Laboratory designed the aircraft receiver and helped NEL with evaluations of the system. NEL prepared the skywave corrections for the western Atlantic, Gulf of Mexico, Caribbean, and West Coast waters off Central America. Scientists in the Netherlands and Britain also provided extensive data. The first four systems were built in Haiku, Hawaii; Forestport, New York; Bratland, Norway; and Trinidad, West Indies. Subsequently, four more stations were added.

Omega provided position fixes worldwide to within half a nautical mile during the day and 1 nautical mile at night. The system required just eight stations, and its receiver was comparatively inexpensive and simple to use. The U.S. services, American and foreign commercial shipping, and private aircraft and boats adopted Omega. Today, Omega is available to all nations and all platforms. As a follow-on, NEL/NELC developed the differential Omega system between 1962 and 1979, a coastal navigation system widely used in the Mediterranean and elsewhere.

Fleet Operational Readiness Accuracy Check Sites (FORACS)

In the 1950s, the Navy had no facilities to calibrate sonars or to determine range and bearing accuracy. The Applied Physics Laboratory at the University of Washington proposed that special facilities be developed for this purpose, and NEL was chosen as lead laboratory and technical director for development. After initial development work at the Applied Physics Laboratory and NEL, construction began in the early 1960s on the first Fleet Operational Readiness Accuracy Check Sites (FORACS) range at San Clemente Island. The FORACS range consisted of three precision-surveyed optical tracking stations on shore, along with various radar, sonar, and optical targets. A central control building containing communications and computer equipment monitored sensor performance data. With the computers at the site, preliminary results could be sent to a ship within 24 hours of the on-range tests.

The first FORACS range became operational in 1965; a second at Nanakuli, Hawaii, followed. Two East Coast ranges were developed at Guantanamo Bay, Cuba, and on Cape Cod, Massachusetts.

Periodic tests of ships' sensors at FORACS ranges led to the discovery of systems errors and shortcomings in documentation that might otherwise have passed unnoticed in the ordinary course of operations.

The usefulness of the FORACS ranges, even now, is in their ability to standardize and repeat tests that had previously been expensive and difficult to arrange. Initially, FORACS addressed the needs of the Fleet's sonars, but the ranges' capabilities were later extended to encompass radar, navigation, and electronic support sensors. Five U.S. sites are presently operational as are two NATO sites. The U.S. sites are located at San Clemente Island, California; Oahu, Hawaii; Fishers Island, New York; Andros Island, Bahamas; and St. Croix, U.S. Virgin Islands. The NATO sites are located on the island of Rennesoy in Norway and on the Greek island of Crete.

Operator collects data from the bridge surface-search radar range/azimuth indicator during FORACS testing.

Laser research. Dr. Erhard Schimitschek (left) and chemist Rick Nehrich (right) stand behind the first laser cavity that produced a visible beam by using a liquid laser material.

Lasers

NEL's work with lasers demonstrated a willingness and an ability to employ emerging technologies to solve field problems. In the early 1960s, a young NEL scientist designed and built the first liquid laser that produced a visible light beam. Born in Czechoslovakia and educated in Germany, NEL's physical chemist, Dr. Erhard Schimitschek, was one of the first scientists to theorize that solutions containing rare-earth chelates (that is, based on very heavy elements) would make suitable lasers. Schimitschek used Europium, Element 66, combined with a ring molecule of benzoylacetonate, to demonstrate a visible beam of coherent radiation, a big step in developing a laser that could be used for communications or surveillance.

NEL used lasers in 1965 in at-sea tests off San Diego that tracked ships during sonar tests. The tests demonstrated that lasers could be used to determine ranges. One example was a jeep-mounted optical detection system for patrolling the perimeters of bases. The system was developed under the Vietnam Laboratory Assistance Program (VLAP) (discussed later). The same laser technology was applied to other systems to mark and optically detect people and vehicles moving along trails and waterways.

During the late 1960s, the emphasis in laser research shifted from extremely high-power lasers to lower power lasers in the blue-green portion of the spectrum that offered greater potential for communications.

Shipboard Communications: Message Processing and Distribution System (MPDS)

In May 1966, as the war in Southeast Asia intensified, Naval Ships Systems Command (NAVSHIPS), in response to an urgent request from the Pacific Fleet for assistance in handling shipboard communications, tasked NEL to design and implement within 1 year a computerized system for handling the internal message traffic aboard USS *Oklahoma City* (CLG 5) (flagship for the Seventh Fleet). For some years, NEL engineers had been addressing the problem as part of a long-term effort (the Naval Ships Advanced Communications Systems project), and they applied findings from that work to the urgent request from the Fleet. Using the NTDS computer and necessary peripheral devices, NEL developed and built the system. Much of the work took place in Battery Ashburn. As in later "rapid prototyping," documentation, maintenance procedures, and training were done simultaneously with development of the system.

The Message Processing and Distribution System (MPDS) was delivered a month ahead of schedule in May 1967. The central MPDS equipment was in the main communications center of the cruiser. Operators manually entered message tapes, and the system then relayed the messages to the appropriate user terminal. The computer memory could store 5200 messages (an impressive number at that time), but microfilming was required for long-term archiving of message traffic. As with many other NEL systems before and since, MPDS relieved communications personnel of much tedious, repetitious work. The MPDS was the first major departure from the precomputer era of manually logging in, distributing, storing, and locating messages. A much more automatic version of MPDS was developed later and installed aboard *Nimitz*-class carriers.

MPDS in Battery Ashburn, 1967. Work on this first automated system for handling shipboard message traffic was completed in less than a year; much of the work took place in Battery Ashburn.

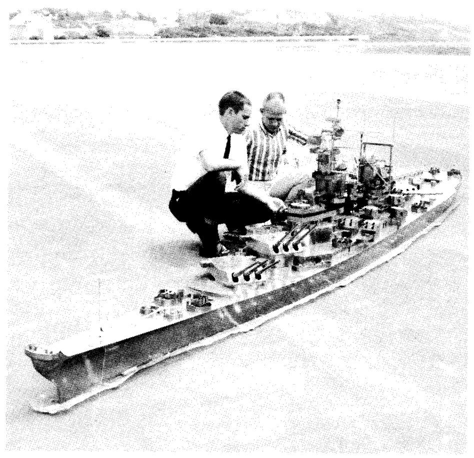
Vietnam Support

Although the Vietnam conflict was primarily a land and air operation, the Navy laboratories played a substantial role in the war. Both NELC and NUWC were involved under the Vietnam Laboratory Assistance Program (VLAP), which DNL established in 1967. Under VLAP, Navy laboratories provided minimally six full-time engineers for the Naval Research and Development Unit–Vietnam.

NELC provided one engineer to serve a 1-year tour of duty as engineer in residence, responsible for navigation, electronics, and other problems that might arise. In addition, NELC engineers made trips to shore or afloat units as the need arose. The engineers were based either in Saigon or Da Nang and spent 3 or 4 days per week helping either the Navy's units in the Mekong River Delta or the Marine Corps north of Saigon. Laboratory representatives sent weekly audio tapes back to Pasadena or San Diego, explaining what they had encountered. The laboratory coordinator referred the problem to the appropriate branch at the laboratory.

Throughout the war, the laboratories solved problems ranging from silencing spark plug noise on small boats to supplying continuous and precise navigational data to help shore bombardment. One task was to develop a variable-intensity polaroid radar filter. Light emitted from radar scopes was too bright for night operations so NELC engineers designed a filter for the river patrol boats. NELC built 200 filters within 2 months of first receiving a request for action. Another quick-reaction project was a navigation improvement system designed to provide continuous, precise navigation data essential to the battleship USS *New Jersey* (BB 62) after it was reactivated for missions in the Tonkin Gulf. In addition, a brass model of *New Jersey* was built at the model range and used in the design of an antenna system. Also, a version of the NEL hand-held sonar, developed to help scuba divers locate small objects, proved useful in Vietnam operations.

Another project affecting operations in Vietnam (although begun at NURDC in 1970) is also noted here: Information on the more common dangerous animals of Southeast Asia was gathered from



Brass model of USS New Jersey *(BB 62) on the turntable of the model range. The model was used in the design of the antenna system for the battleship when it was reactivated for missions in the Tonkin Gulf in 1968.*

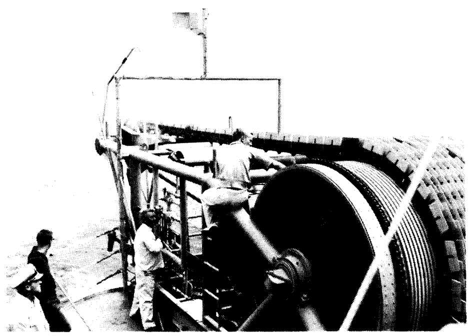
Directional Finder. VHF/DF antenna (mounted on bow) aboard PBR 208 support craft developed under the Vietnam Laboratory Assistance Program.

several sources including underwater demolition teams (UDTs), the Marine Corps, and civilian personnel. NURDC scientists prepared a handbook to provide field personnel with the best information on the safest way to deal with sea snakes, land snakes, and crocodiles. The distributed handbook helped to reduce fears based on misinformation and was of valuable use to field and medical personnel.

In time, VLAP led to the Navy Science Assistance Program (NSAP). NSAP assigns laboratory researchers to operational units for 1-year tours of duty and provides a means of appraising the practical needs and difficulties encountered by the Fleet.

Thermal Mapping of the Ocean

During the early 1960s, NEL developed a thermistor chain to map the thermal structure of the various layers in the ocean. The results obtained by the thermistor chain illustrated the way in which undirected "pure science" supported the military objectives of the Navy's laboratories as a whole. The chain, 900 feet long, was towed in a near vertical position by an NEL research ship. Every 27 feet along the chain, a thermistor bead sensor read the water temperature. This information was transmitted to the research ship, whose instruments recorded the resulting depth, distance and time charts in a line of isotherms. Much of this work took place in the Gulf of California or in the Pacific off San Diego. The data were used to map the ocean acoustically and to support transducer and sonar development. Using the chain, other NEL oceanographers mapped segments of the Bering Sea.

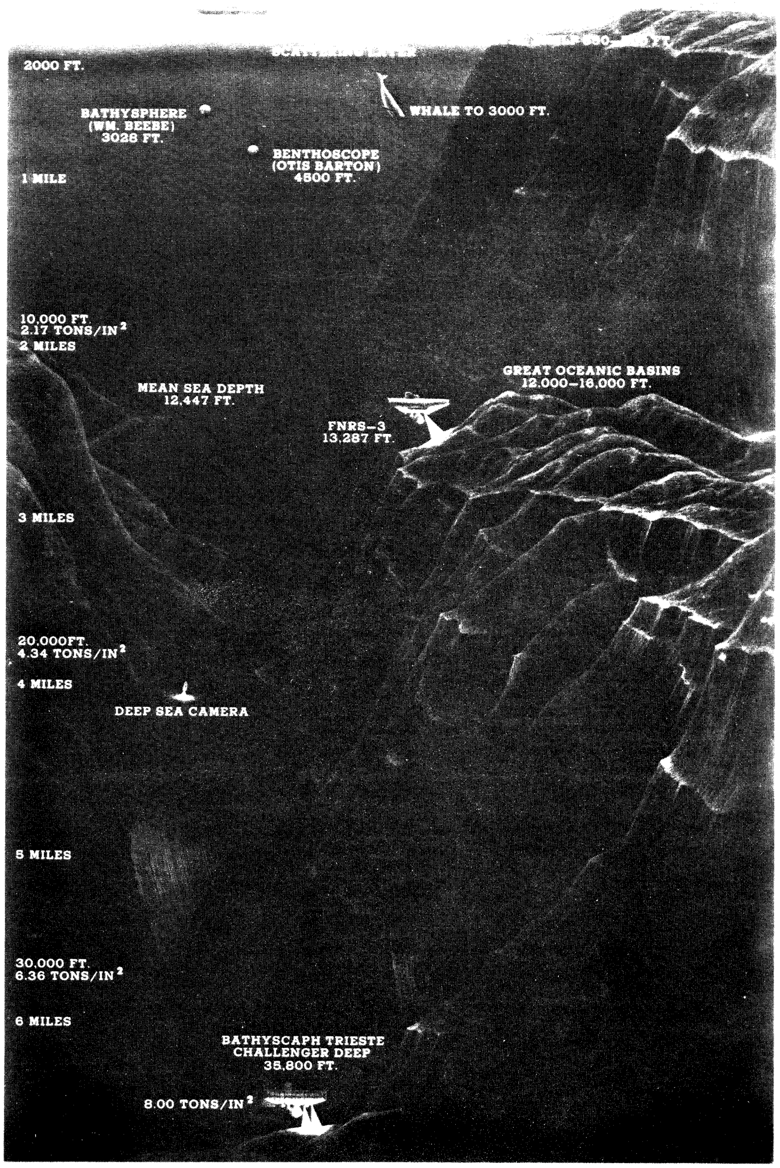


Thermistor chain developed to map the thermal structure of the ocean.

Deep Submergence: *Trieste*

On 23 January 1960, Lieutenant Don Walsh of NEL and Auguste Picard's son, Jacques, took the bathyscaph *Trieste* into the Challenger Deep Trench in the Pacific Ocean, 200 miles southwest of Guam. Before returning after 9 hours, they took *Trieste* to a world-record 35,800 feet, nearly 7 miles beneath the sea. The record still stands. Picard ended his contract with ONR shortly afterwards, but Walsh and his Navy colleague, Lieutenant L. A. Shumaker, continued to pilot *Trieste* in a series of NEL-directed expeditions in 1961 and 1962. Equipped with plankton samplers, a salinity monitor, temperature probes, and water sampling bottles, *Trieste* usually made one dive a week, taking the winter months off for refitting and overhauling.

Trieste's last dives, if not the most celebrated, were certainly the most poignant. On 10 April 1963, the new nuclear submarine USS *Thresher* (SSN 593) was lost 270 miles east of Boston, Massachusetts. The Navy launched an immediate rescue effort, but rescuers soon learned that there would be no survivors. In the depths at which *Thresher* had been lost (8400 feet), the submarine would have imploded from the pressure.



Trieste began diving for *Thresher* in June 1963. Under Lieutenant J. Brad Mooney, the officer-in-charge (later Chief of Naval Research), and Kenneth Mackenzie, NEL scientist-in-charge of the Deep Submergence Program, *Trieste* set to work at depths of over 8000 feet. *Trieste* proved able to navigate on the Atlantic Ocean bottom and surveyed the bottom systematically. *Trieste*'s crew located pieces of *Thresher*, which they photographed. After a brief overhaul, *Trieste* returned in August and found major pieces of wreckage and used a newly fitted mechanical arm to retrieve a section of piping. The *Trieste* operations led to determining what caused the loss of the submarine and what design changes needed to be made to avoid future failures.

On 23 January 1960, Trieste *descended into the Challenger Deep to a record 35,800 feet.*

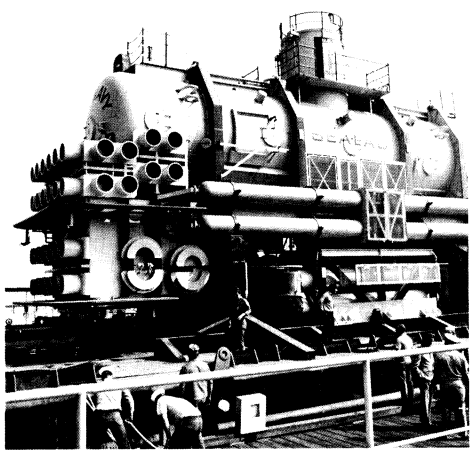
Undersea Habitat: Sealab II

Following the loss of *Thresher*, the Navy established the Deep Submergence Systems Project (DSSP) to develop techniques and equipment to improve capabilities in the deep ocean environment. Both NEL and NOTS Pasadena played important roles in several DSSP programs. In 1965, as part of its Man-in-the-Sea program, DSSP conducted the Sealab II experiment at a site off the coast of La Jolla, California. The Sealab II experiment consisted of three 10-man teams living and working in the Sealab undersea habitat at a depth of 205 feet. Each team would spend 15 days underwater. The project was conducted for a total of 45 days—from 28 August to 14 October 1965.

An NEL diver and photographer, Bill Bunton, participated in Sealab II, as did the original Project Mercury astronaut, Scott Carpenter. Sealab II's living compartment included a laboratory, galley, and bunkroom. In their self-contained environment, aquanauts breathed a mixture of 80-percent helium, 16-percent oxygen, and 4-percent nitrogen. The project had three phases: human performance measurement, oceanography, and salvage of a Navy jet that had been sunk for the experiment. Sealab II conducted several diving and decompression experiments, including total gas saturation dives, deep excursion dives without decompression, and exploration. The aquanauts ate fish, crabs, and even raw plankton, as part of their effort to demonstrate that aquanauts could function at such depths. One of the highlights of Sealab II was a conversation between Scott Carpenter, 200 feet underwater, and astronaut Gordon Cooper, who was circling the earth in a capsule 200 miles in space.

NOTS Pasadena provided the staging vessel that the Long Beach Naval Shipyard modified to NOTS specifications. And NOTS Pasadena installed and maintained all the special equipment, including the decompression chamber and the personnel transport capsule. While Sealab II experiments were proceeding, NOTS personnel provided all the surface support, which included operating the staging vessel and handling numerous small boats.

NOTS Pasadena also provided a marine mammal for tests. The second team of aquanauts conducted tests with Tuffy, a bottlenose dolphin, trained to respond to sound signals, to determine whether such an animal could be useful to persons in the sea. Initially, Tuffy did not respond as expected, probably because of the new surroundings and noise from the surface support ship. However, Tuffy soon began making several dives from the surface to 205 feet and delivered mail, tools, and messages. In another test, Tuffy carried a guideline from the habitat to an aquanaut who was signalling that he was in need of assistance. The tests demonstrated that trained dolphins could work untethered in the open sea with great reliability.



Sealab II undersea habitat.

A Sealab II diver determining the orientation of a gorgonian coral.

Marine Mammal Program

The Navy's Marine Mammal Program had its origin in the acquisition, in 1960, of a Pacific white-sided dolphin for hydrodynamic studies. Scientists at NOTS China Lake and Pasadena had heard accounts of the hydrodynamic efficiency of dolphins (sometimes called porpoises to distinguish the dolphin-mammal from the dolphin-fish). Since NOTS was in the business of designing and developing torpedoes, it seemed reasonable to find out whether dolphins did, in fact, have special characteristics that might be applied to the design of underwater missiles.

Work with the white-sided dolphin, named Notty, revealed no unusual physiological or hydrodynamic capabilities, but it was suspected that conditions in the long testing tank in which she swam might have affected her performance. NOTS scientists and engineers looked for an appropriate site at which to establish a small research facility to continue their investigation of dolphins.

They found such a site at Point Mugu, California, where the Pacific Missile Range and Naval Missile Center were located. By coincidence, a group in the Life Sciences Department of the Naval Missile Center was also proposing to undertake studies of marine life, including dolphins. Mugu Lagoon, the last such body of protected water on the Southern California coast, was seen as a great asset for such work.

As a result of these mutual interests, and with encouragement from the Office of Naval Research, a modest facility for research and exploratory development gradually evolved on a sand spit between the lagoon and the ocean at Point Mugu. The program got underway in 1963. Primary interest was in marine mammals—the study of their specially developed senses and systems, such as sonar and deep-diving physiology—and also how marine mammals might be used to perform useful tasks.

Scientists from universities nationwide visited the facility to observe the pioneering work of Sam Ridgway (the first veterinarian to work full-time with dolphins) and to learn how marine mammals have adapted to life in the sea. Many people had thought it impossible to work with a dolphin free in the open sea—where it has access to abundant food, is free to join herds of its own species, and is free to roam the ocean. Yet trained dolphins such as Tuffy continued to demonstrate with Sealab and other projects, a motivation to return and a capability to perform with a high degree of precision and reliability. Diving at 600 or 1,000 feet in the ocean is a dangerous undertaking for humans, but for dolphins this is a natural act of daily life, almost entirely without danger.

In 1967, the Point Mugu facility and its personnel, both of NOTS and the Naval Missile Center, were placed under NUWC, with headquarters in San Diego. Following the opening of the Hawaii laboratory on Kaneohe Bay, some personnel and animals at Point Mugu transferred to Hawaii, and later the rest of the Point Mugu operation moved to San Diego to continue research and development in marine biosciences.

Remotely Operated Vehicles (ROVs)

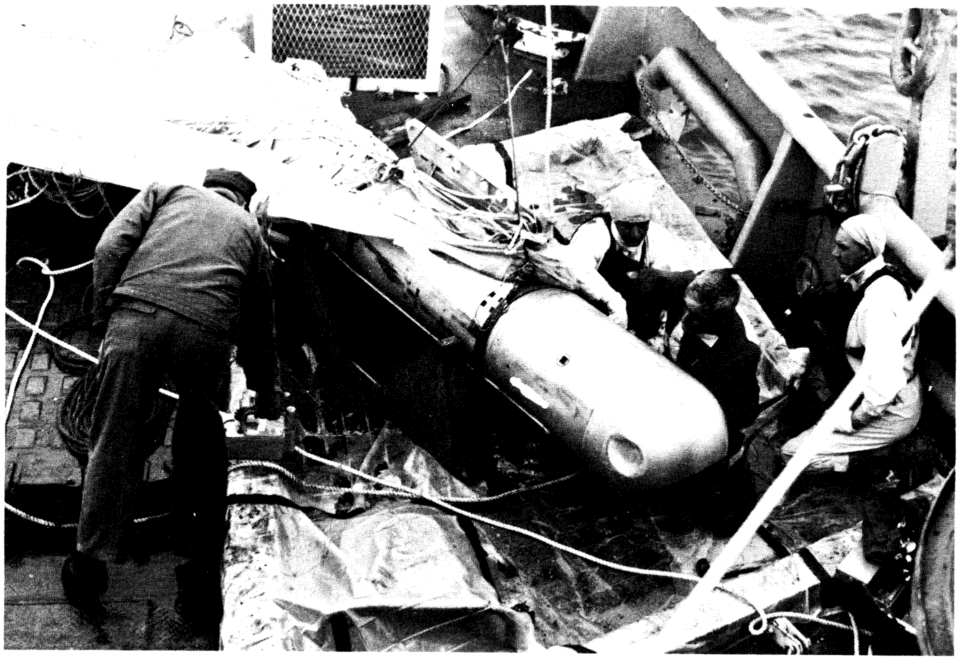
During the 1960s, NOTS Pasadena began to develop a new mission. As part of its work at the Navy's San Clemente Island test range as well as its own waterfront activities at Long Beach, NOTS carried out several basic tasks connected with testing underwater ordnance. When testing torpedoes, NOTS engineers tried whenever possible to recover the torpedo and its exercise head, that is, the data-recording gear that replaced the warhead in a weapon under development. Having the exercise head allowed researchers to assess performance and to locate faults.

Although the test torpedoes were designed to float to the surface at the end of their run, occasionally units sank to the seafloor. When the torpedoes sank in shallow water (to depths of 200 feet), Navy divers were able to recover them. However, as torpedoes and other weapons were ranged in deeper and deeper waters, other recovery means were required.

During the early 1960s, NOTS Pasadena engineers developed a remotely operated vehicle known as the Cable-Controlled Underwater Recovery Vehicle (CURV). This vehicle was equipped with a sonar, a television, and a claw designed to recover torpedoes at depths to 2000 feet. CURV was successfully demonstrated in 1965.

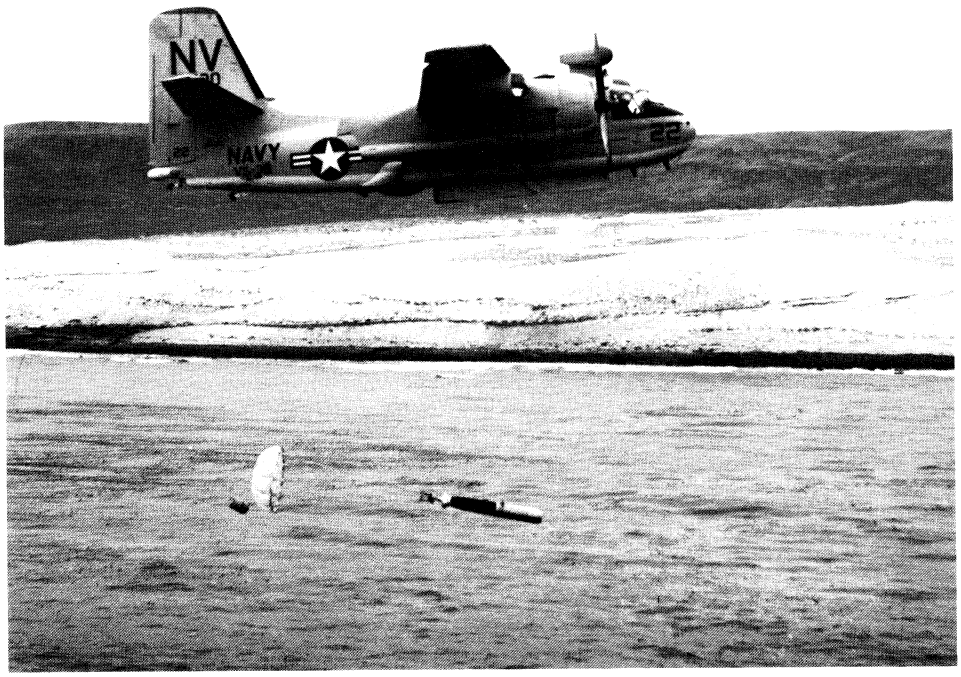
CURV was put to further use in early 1966. In January 1966, an Air Force B-52 collided with a KC-135 tanker off Palomares, Spain. The bomber was carrying four hydrogen bombs. Three of the unarmed bombs fell into the Spanish countryside, where they were quickly recovered. The fourth dropped into the Mediterranean. Local fishermen gave the Navy a good idea of the bomb's approximate location, and a small armada of search and recovery vessels was assembled. The manned submersible *Alvin*, operated by the Woods Hole Oceanographic Institute, succeeded in locating the bomb but had no way of recovering it. In fact, *Alvin* got tangled in the parachute shroud of the bomb and was almost lost.

CURV was the only system that could both search for and recover objects. A new cable was quickly spliced onto CURV to extend its range. The vehicle and its crew, headed by Howard Talkington, were airlifted to Spain. On its third dive, CURV located the bomb, grabbed the lines of its parachute, and, early on the morning of 7 April, hauled the lost H-bomb to the surface.



Hydrogen bomb rests on deck of USS Petrel *(ASR 14) after being recovered during CURV operation.*

Following CURV's success in the Mediterranean, NOTS Pasadena began planning a CURV with a deeper operational capability. During the planning, NOTS found that CURV I was not reliable enough for its range operations. Two CURV systems were developed concurrently: CURV II to operate more reliably during range operations and CURV III to respond to national emergencies. CURV II retained most of the features of CURV I but was modified to replace inadequate components. CURV III used the best of the original CURV concept but was otherwise a new system. CURV III was designed with an initial depth capability of 7000 feet, which was later increased to 10,000 feet.



Mk 46 Mod 0 launched by an ASW aircraft during sea operations test program. The Mk 46 can also be launched by ASROC, helicopters, and surface ship tubes.

Torpedo Mk 46

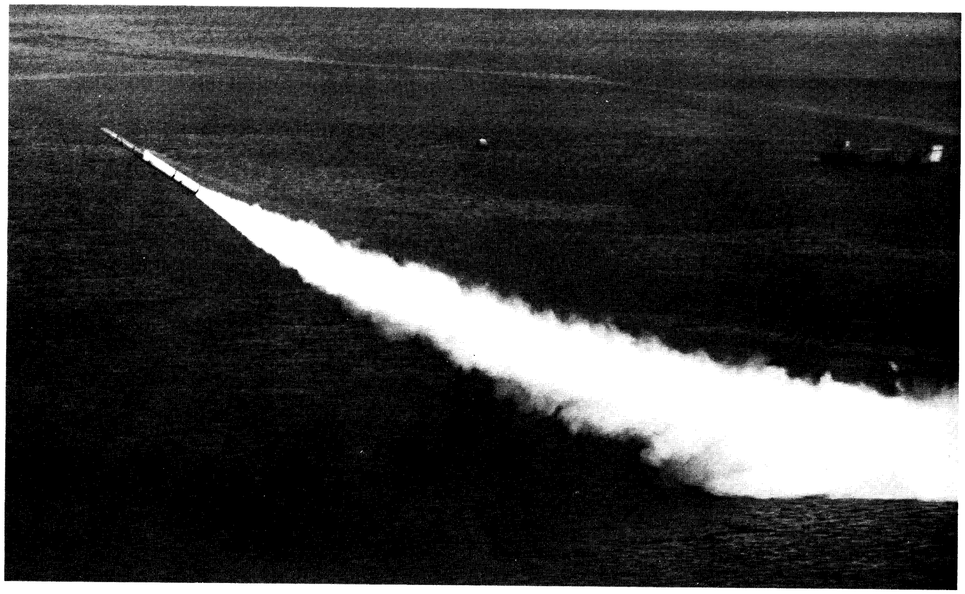
When the Torpedo Mk 44 reached the Fleet in 1958, R&D on a more capable successor had already begun at NOTS Pasadena. NOTS would not only design and develop the new torpedo but would oversee its manufacture, help introduce it to the Fleet, and maintain and upgrade it once in service. NOTS engineers also addressed the design of the torpedo's acoustic homing system. The torpedo could home-in on its target with an active-passive acoustic head and either follow the target's radiated noise or, if the target were silent, search for it with active sonar. Thus, the guidance system functioned in two modes, termed "passive/active circle," or "active snake mode," to detect and then localize enemy submarines.

Although torpedo development might easily be thought of as primarily applied engineering, the development of lightweight torpedoes drew heavily upon relevant fundamental research. Indeed, in the mid-1960s, about 10 percent of the annual budget of NOTS Pasadena went toward basic research. The most significant research and development that went into the Mk 46 was the REVEL guidance system. Until the REVEL system went into the Mk 46, torpedo guidance had not changed appreciably since World War II. The Mk 46 continues today as the Navy's standard lightweight torpedo.

In a related effort to this torpedo work, the chemistry group at NOTS Pasadena did considerable research on how polymers might be used to reduce hydrodynamic drag. Even very small concentrations of these synthetic coatings and natural substances could reduce turbulence and thus extend the range and speed of torpedoes. Commercial applications to internal pipe-flow have since been implemented in fire-fighting systems and in long-distance oil pipelines.

Submarine Rocket (SUBROC)

Developed as an outgrowth of earlier work to determine the feasibility of systems such as ASROC, the submarine rocket (SUBROC) system was essentially an underwater guided missile that could be fired from above or below the surface. The Naval Ordnance Laboratory at White Oak, Maryland, developed the project and Goodyear Aerospace Corporation was the prime contractor. NOTS Pasadena was tasked with carrying out the underwater firings of SUBROC at San Clemente Island. The SUBROC system was designed to detect a submarine at long range, compute its course and speed, and fire a missile. In 1963, NOTS Pasadena accomplished the first successful firing of a SUBROC flight test vehicle from a submarine off San Clemente Island.



SUBROC. Underwater firing of SUBROC off San Clemente Island.

ASW Fire Control Systems (FCSs)

The Fire Control Group (FCG) Mk 111 was developed by NOTS Pasadena to compute and control the placement of ASROC-delivered payloads. First-production FCG Mk 111 sets entered the Fleet in 1960.

NOTS developed the FCG Mk 111 to control and fire all ASROC missile configurations at ranges exceeding an order of magnitude over previous ASW weapons. The FCG Mk 111 was significant in that it introduced digital equipment into Navy vessels and implemented the first successful math model of a complex weapon system. A large-screen optical plotter was also developed to display the tactical geometry of the ASW attack scenario. The development of the FCG Mk 111 allowed Navy vessels to deliver ASW weapons at extended ranges with great accuracy and minimized the exposure of the firing vessel to counterattack.

Between 1959 and 1961, NOTS Pasadena conducted an R&D development program to include other ASW weapons in addition to ASROC in ASW fire control equipment. By modifying the FCG Mk111 math model, NOTS developed a more versatile ASW fire control system (FCS), the FCS Mk 114.

The FCS Mk 114 allowed Navy vessels to deliver a variety of ASW weapons more accurately. First-production FCS Mk 114 sets entered the Fleet in 1962. The tactical versatility of the FCS Mk 114 provided the capability to effectively meet the nuclear submarine threat in both stand-off and search-and-destroy ASW missions.

In the late 1960s, conceptual development work was performed that led to production, in the 1970s, of the Mk 116 underwater fire control system. This system became the first surface ASW digital fire control system to communicate directly to a digital launcher. The entire computer programming for the Mk 116 Mod 1 was performed in-house. Using the modular programming concept, the computer program proved extremely reliable and adaptable to changes. It integrated the standard equipment of computer (UYK-7) and display console (UYA-4) to ASW use and thus helped to standardize shipboard equipment.

Underwater Missile-Launch and Propulsion Technology

Over the years, NOTS/NUWC scientists and engineers participated in developing the concepts and technology for underwater missile launch. Every underwater-launched missile in use by the U.S. Navy continues to undergo full-scale development testing at the San Clemente Island test range prior to certification for use onboard U.S. submarines.

Also, NOTS engineers at the Morris Dam facility near Pasadena led the way in the significant development of new torpedo propulsion concepts. The requirements for high speed through the water, silent running, and maximum range necessitated several solutions. Experiments on new chemical fuels, high-energy batteries, prime movers, and thrust-producing mechanisms all contributed to further advances in the Navy's torpedo program.